Measurements of natural background radiation in the underground laboratories of the BSUIN and EUL projects.

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BSUIN and EUL projects

— **BSUIN - Baltic Sea Underground Innovation Network**
  — The project aims to develop the capabilities of ULs in order to improve their service offering as a capacity for innovation, and to create a network of the Baltic Sea Region's ULs in order to provide the users an easy access and environment for business development and innovation.
  — 5 Work packages
    — WP2: Characterization of Underground Laboratories
      — A.2.2 Natural radioactive background characterization

— **EUL – Empowering Underground Laboratories Network Usage**
  — EUL is an extension stage project of the regular BSUIN project.
  — The main goal is to test the developed business and service concepts for the established network of underground laboratories and for the individual laboratories.
  — 4 Work packages
    — WP3: Customer Relationship Management of the ULs
      — A.3.3 Optimal underground facility selection for the UL customers

More information on both projects were presented in the virtual session in the presentation:
J.Kisiel et al., *Underground laboratories in the Baltic Sea Region - EUL Project*
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BSUIN and EUL Underground Laboratories

**Partner Laboratories**
- Callio Lab, Pyhäalsalmi (Finland),
- Äspö Hard Rock Laboratory, Oskarshamn (Sweden),
- TU-Freiberg’s Research and Education Mine “Reiche Zeche” (Germany),
- Conceptual Lab development co-ordinated by KGHM Cuprum R&D centre (Poland),
- UL of Khlopin Institute (Russia),
- Ruskeala marble mine (Russia).

**Associated Laboratories**
- Experimental Barbara mine (Poland),
- Hagerbach Test Gallery (Switzerland).
**Callio Lab (Finland)**
- Copper, zinc, and pyrite mine.
- The oldest and deepest base metal mine in Europe.
- Location: in the city of Pyhäsalmi in Central Finland.
- 7 Labs (levels: 75 - 1440 m).
- Measurements were made in Lab2 at a depth of 1430 m (4 000 m w.e.).

**Reiche Zeche mine (Germany)**
- Historic ore mine.
- Location: Eastern Erzgebirge Mountains Scientific and didactic mine of the Bergakademie Freiberg University of Technology (TUBAF).
- Two shafts: Reiche Zeche and Alte Elisabeth.
- Measurements were made on the first level of 150 m (390 m w.e.).
Measurements of Natural Radioactivity

**In-situ gamma measurements**
- γ spectrometry with HPGe detector

**Measurement of radon concentration in air**
- RAD7 detector

**Rock sample analysis**
- α and γ spectrometry

**Water sample analysis**
- LSC, α spectrometry

RAD7 detector

γ spectrometry

α spectrometry

LSC technique
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**In-situ γ-ray measurements**

- Measurements were performed in:
  - **server room** - Reiche Zeche mine (dimensions 3 m x 3 m x 2.2 m),
  - **Lab 2** - Callio Lab (dimensions 9 m x 15 m x 8 m).

- Equipment used for measurements (Canberra Industries, Inc., USA):
  - GR4020 portable spectrometer, HPGe coaxial detector (40% relative efficiency),
  - InSpector™ 2000 multichannel analyser (for data collecting),
  - Genie™ 2000 v.3.2.1 software package (for spectra analysing)

- Before measurements, two calibrations were made:
  - the energy calibration: 7 sealed radioactive sources (\(^{133}\)Ba, \(^{137}\)Cs, \(^{54}\)Mn, \(^{57}\)Co, \(^{109}\)Cd, \(^{22}\)Na, \(^{60}\)Co),
  - the efficiency calibration: the In Situ Object Counting System (ISOCS™) - a mathematical calibration software was used.

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<table>
<thead>
<tr>
<th></th>
<th>Reiche Zeche server room(^1)</th>
<th>Callio Lab (Lab2)(^2)</th>
<th>CUPRUM (salt cavern P1)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Effective dose rate</strong> [(\mu\text{Sv/h})]</td>
<td>0.036±0.008</td>
<td>0.158 ± 0.029</td>
<td>0.002(^3)</td>
</tr>
<tr>
<td><strong>Gamma-ray flux density</strong> [(\text{cm}^2\text{s}^{-1})]</td>
<td>2.8 ± 0.8</td>
<td>12.7 ± 1.5</td>
<td>0.124 ± 0.002(^4)</td>
</tr>
<tr>
<td><strong>Counts per second</strong></td>
<td>516.95±0.05</td>
<td>654.75±0.05</td>
<td>-</td>
</tr>
<tr>
<td><strong>Energy range [keV]</strong></td>
<td>[7-3150]</td>
<td>[7-3150]</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^3\)J.Kisiel et al., Acta Phys Pol B, 41(2010)7,  
\(^4\)K.Polaczek-Greli et al., J Radioanal. Nucl. Chem. 308 (2016) 773 – 780,
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Radon concentration in air

The measurement was done in the server room using a RAD7 electronic radon detector (Durridge Company, Inc.), located near the gamma-ray spectrometer.

Radon concentration was obtained from 24 or 48 measurements (1 h-long each).

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Reiche Zeche server room$^1$</th>
<th>Callio Lab (Lab2)$^2$</th>
<th>CUPRUM salt cavern$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{222}$Ra [Bq/m$^3$]</td>
<td>805.1±10.4</td>
<td>247.5±26.3</td>
<td>12±4 - 49±8</td>
</tr>
</tbody>
</table>

3J.Kisiel et al., Acta Phys Pol B, 41(2010)7,
234,238U concentration in water samples

The measurements of 234,238U isotopes concentration were performed with the use of α spectrometry technique (7401VR from Canberra (Packard).

Before measurements, the radiochemical procedure was made:
- Samples were acidified with HNO₃.
- To each water sample, added the standard 232U of known activity.
- The separation of uranium was done with the use of the anion exchange resin Dowex 1×81.
- A thin α-source was prepared by coprecipitation with NdF₃ and filtration.
- The Minimum Detectable Activity (MDA) was equal to 0.5 mBq/l (0.5 l initial sample volume, 2 days measurement time).

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Reiche Zeche server room [mBq/l]²</th>
<th>Callio Lab (Lab2) [mBq/l]³</th>
<th>Outside PH-500907</th>
<th>PH-102</th>
<th>PH-103</th>
</tr>
</thead>
<tbody>
<tr>
<td>²³⁸U</td>
<td>150.4±5.2</td>
<td>6.5±0.7</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td></td>
</tr>
<tr>
<td>²³⁴U</td>
<td>142.4±4.9</td>
<td>11.1±0.9</td>
<td>4.9±0.7</td>
<td>0.8±0.2</td>
<td></td>
</tr>
<tr>
<td>²³⁴U/²³⁸U</td>
<td>0.95±0.5</td>
<td>1.70±0.23</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

1. J. Suomela, Method for Determination of U-Isotopes in Water, Swedish Radiation Institute, Stockholm, 1993,
The measurements of $^{226,228}\text{Ra}$ activity concentrations were done by using the LSC technique (1414 WinSpectral $\alpha/\beta$ LSC (Wallac) and 1410 Tricarb $\alpha/\beta$ LSC).

Before measurements, the chemical procedure$^1$ was applied.

The time of measurement sample was one h (once per day over a period of one month until a secular equilibrium between $^{226}\text{Ra}$ and its daughters was reached).

The MDA for radium isotopes: $^{226}\text{Ra}$: 0.015 Bq/l, $^{228}\text{Ra}$: 0.04 Bq/l (1.5 l initial sample volume).

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Reiche Zeche server room [mBq/l]$^2$</th>
<th>Callio Lab (Lab2) [mBq/l]$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Outside PH-500907   PH-102   PH-103</td>
</tr>
<tr>
<td>$^{226}\text{Ra}$</td>
<td>&lt;15</td>
<td>54.9±1.3          116.6±2.7   15.1±0.4</td>
</tr>
<tr>
<td>$^{228}\text{Ra}$</td>
<td>&lt;40</td>
<td>36.9±2.1          10.7±4.5    6.1±0.9</td>
</tr>
</tbody>
</table>

$^1$Polish Norm PN - 89 Z - 70072, 1989,
The measurements of $^{234,238}$U activity concentrations were performed with the same technique as for the water sample - α spectrometry technique (7401VR from Canberra, Packard).

Before measurements, the radiochemical procedure was made:

- Rock samples were dried and crushed with a ball mill and etched with hot acids: HF, HNO$_3$, and HCl with H$_3$BO$_3$.
- Uranium was preconcentrated with iron and co-precipitated at pH 9.
- The separation of uranium was done with the use of the anion exchange resin Dowex 1×8.$^1$
- The sample for α-spectrometric measurement was prepared by co-precipitation of U with NdF$_3$ and deposition on polypropylene disks.
- The Minimum Detectable Activity (MDA) was 0.4 mBq per sample for uranium isotopes ($^{234,238}$U).

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<th>CUPRUM (salt cavern)$^4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}$U [Bq/kg]</td>
<td>32.4±2.3 rock</td>
<td>57.4±3.7-87.1±3.6 concrete 1.4±0.2-11.4±1.4 rock</td>
<td>0.016±0.003-0.40±0.06 salt 0.82±0.09 anhydrite</td>
</tr>
<tr>
<td>$^{234}$U [Bq/kg]</td>
<td>34.4±2.4 rock</td>
<td>53.9±3.5-89.2±3.7 concrete 1.6±0.2 - 10.3±1.3 rock</td>
<td>0.021-0.38±0.05 salt 0.76±0.24 anhydrite</td>
</tr>
<tr>
<td>$^{234}$U/$^{238}$U</td>
<td>1.06±0.11 rock</td>
<td>0.94±0.09-1.02±0.60 concrete 0.90±0.15-1.20±0.17 rock</td>
<td>-</td>
</tr>
</tbody>
</table>

The measurements of radioisotopes concentration were performed using the gamma spectrometry method with a lead-shielded HPGe detector.

Before the measurements, rock samples were dried, crushed, ground, and stored in a Marinelli container (for one month to achieve the secular equilibrium in thorium and uranium series).

The HPGe detector has a 60.7 mm crystal diameter and a Cryo-Pulse 5 Plus, an electrically powered cryostat, and a relative efficiency of 20%.

The radioactivity concentrations were calculated based on a standard prepared from certificated materials from the Central Laboratory for Radiological Protection in Poland.

The activity of $^{226}$Ra was calculated as the weighted mean of the values obtained from the $^{214}$Pb (295.2; 351.9 keV) and $^{214}$Bi (609.3; 1120.3 keV) isotopes, whereas the activity of $^{228}$Ra from the gamma lines 338.3 keV and 911.1 keV originating from $^{228}$Ac, while the activity of $^{40}$K from the 1460.8 keV line.
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$^{226}$Ra, $^{232}$Th, $^{40}$K concentration in rock samples

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</tr>
</thead>
<tbody>
<tr>
<td>$^{226}$Ra [Bq/kg]</td>
<td>43.8±0.4 rock</td>
<td>40.2±1.6 – 91.0±2.4 concrete 8.1±0.4 – 58.0±2.3 rock</td>
<td>0.11±0.004-0.008 salt 0.52 anhydrite</td>
</tr>
<tr>
<td>$^{232}$Th [Bq/kg]</td>
<td>31.5±0.6 rock</td>
<td>34.4±1.5 – 53.8±3.1 concrete 2.6±0.3 – 46.6±2.4 rock</td>
<td></td>
</tr>
<tr>
<td>$^{40}$K [Bq/kg]</td>
<td>1049±17 rock</td>
<td>662±53 – 1136±47 concrete 104±10 – 272±24 rock</td>
<td>2.1-4.0 salt not determined-anhydrite</td>
</tr>
</tbody>
</table>

Summary

The research results on natural background radiation in selected underground laboratories of the BSUIN and EUL project were presented and compared with previous studies at the Polkowice-Sieroszowice mine (Conceptual Lab development co-ordinated by KGHM Cuprum R&D center, Poland).

The in-situ measurements and laboratory analyses of rock and water samples were performed using $\alpha$, $\gamma$ spectrometry, and LSC technique.

The most important results:

- **radon concentration in the air** (the highest value at Reiche Zeche mine),
- **effective dose rate, gamma-ray flux, counts per second** (the highest values for Callio Lab),
- **concentrations of uranium isotopes ($^{234,238}$U) in water and rock samples** (water: about 20 times higher concentrations for Reiche Zeche than Callio Lab; rock: the highest concentrations for samples from Callio Lab),
- **concentrations of radium isotopes ($^{226,228}$Ra) in water samples** (values below the MDA for Reiche Zeche mine),
- **concentrations of radium ($^{226}$Ra), thorium ($^{232}$Th), and potassium ($^{40}$K) isotope in rock samples** (the highest concentrations in samples from Callio Lab and the lowest in samples from the Polkowice-Sieroszowice mine).
Thank You!